FINAL TECHNICAL REPORT

NAGW-1200: Uranus Data Analysis Program

Uranian rings - dynamics and particle size distribution

October 1987 - September 1990

The overall goals of this work were (1) to constrain the particle size distribution in the Uranian rings, and (2) to re-examine the dynamics of narrow eccentric rings, via correlative studies of Voyager and ground-based occultation data. Specific results were obtained in the following areas; most are to be published in the review chapter "The dynamics and structure of the Uranian rings", by R. G. French, P. D. Nicholson, C. C. Porco, and E. A. Marouf, in the forthcoming book "Uranus" in the University of Arizona planetary science series. The results of item (b) are not yet written up for publication.

(a) Multi-wavelength optical depth comparisons.

The equivalent depths (i.e., the radially-integrated optical depths) for all Voyager stellar occultation profiles of the Uranian rings (UVS and PPS data) were determined, and compared with the corresponding quantities derived from the Voyager RSS experiment (Gresh et al., 1989) and from ground-based data (e.g., French et al., 1986; see also item (b) below). To our surprise, it was found that, when corrected for diffraction effects (Cuzzi 1985), the optical depths of the 9 pre-Voyager rings are constant over the wavelength range 0.11 μm - 3.6 cm (see Fig. 1). The implication, confirmed by other studies and by the observed extinction efficiency of the rings, is that almost all the ring cross-section is in particles of radius $\gtrsim$ 1 cm.

(b) Re-analysis of ground-based occultation profiles.

High-quality occultation profiles obtained at Palomar Observatory in June 1982 and May 1985 were analyzed to obtain rigorous event times, radial ring widths, and mean optical depths for a total of 36 cuts across the 9 rings. The analysis involved the development of a nonlinear least-squares diffraction model code, based on that described by Elliot et al., (1984). The results are not yet written up, but a sample of the fitted data is shown in Fig. 2.

(c) Weak dynamical effects on the rings.

The sensitivity of the apsidal precession rates of the 6 eccentric Uranian rings (now known to ~1 part in 10^4, typically) to currently unmodelled dynamical effects was investigated, in collaboration

with Dr. R. French of Wellesley College. It was found that it may be possible to separate the effects due to the ϵ ring shepherd satellites, Cordelia and Ophelia, from those due to the larger satellites and Uranus' J_6. Implementation of the proposed analysis, and the possible determination of the shepherd satellite masses, is dependent on a new 3rd order theory of secular perturbations being developed by N. Borderies and P.-Y. Longaretti. Our analysis will be completed once the new 3rd order precession rates are available.

(d) Width variations in the Uranian rings.

Again in collaboration with R. French, we have examined the width variations of the narrow Uranian rings using the Voyager occultation data sets, as well as the existing body of ground-based data. Unlike the somewhat wider α, β, δ and ϵ rings, the 1-5 km wide rings γ, 6, 5, and 4 show no systematic width-radius or width-longitude relations. It is possible that the substantial width variations exhibited by these four rings are controlled by higher-order internal modes of oscillation than the m=1 and m=0 modes which control their overall shapes, but this hypothesis is as yet untested.

Publications related to UDAP research:

J. B. Holberg, P. D. Nicholson, R. G. French and J. L. Elliot (1987). "Stellar occultation probes of the Uranian rings at 0.21 and 2.2 microns: a comparison of Voyager UVS and earth-based results." *Astron. J.* **94**, 178.

M. R. Showalter and P. D. Nicholson (1987). "Meter-sized particles in the Uranian rings." *B.A.A.S.* **19**, 885 (Abstract).

R. G. French, P. D. Nicholson, C. C. Porco, and E. A. Marouf (1991). "Dynamics and structure of the Uranian rings." In "Uranus", J. Bergstrahl (ed.), University of Arizona Press.

P. D. Nicholson and L. Dones (1991). "Planetary rings." *Quadrennial report to the I.U.G.G., Reviews of Geophys.*, Suppl. p. 313.

References

Cuzzi, J. N. (1985). *Icarus* **63**, 312.

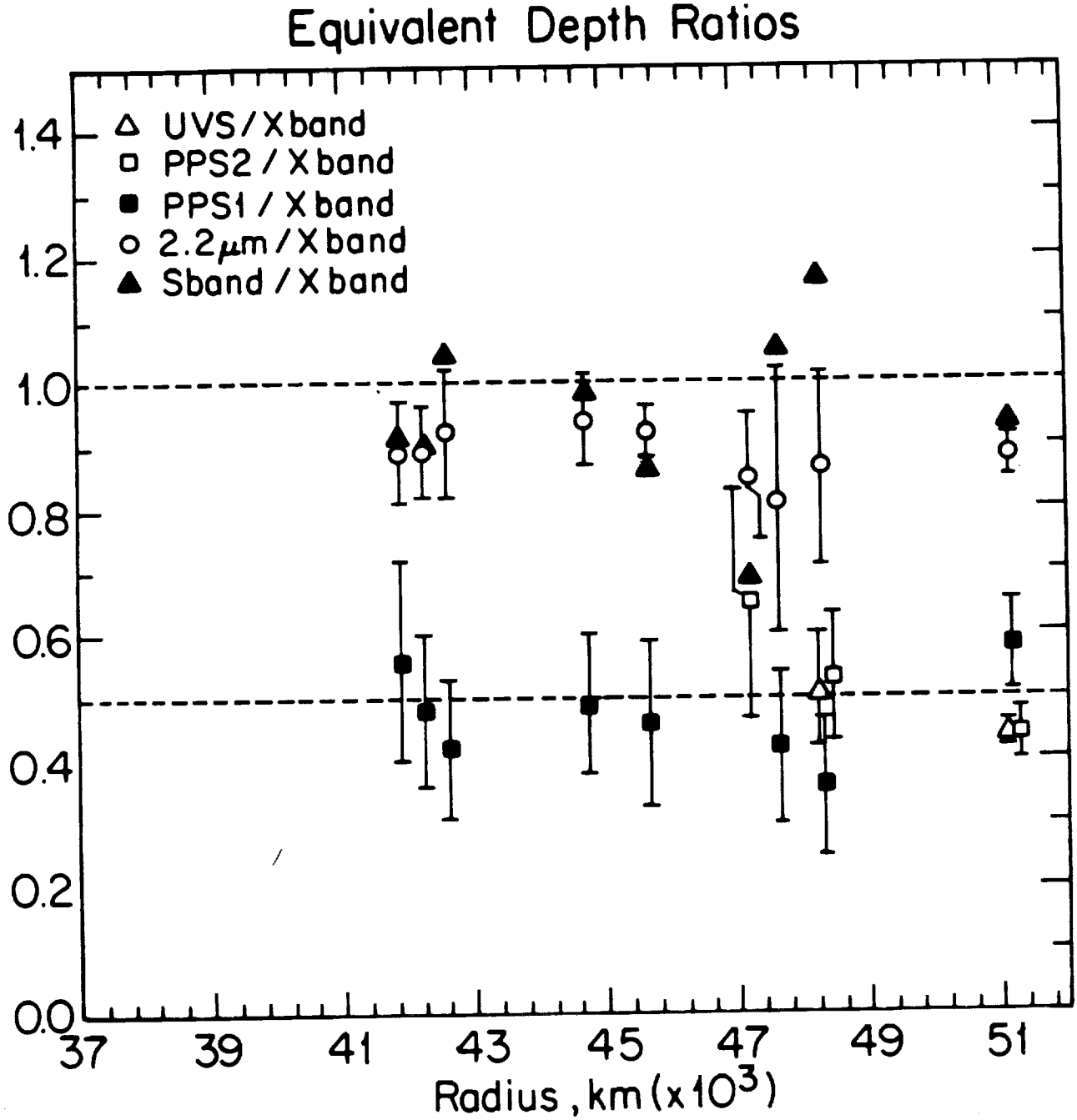
Elliot, J. L., R. G. French, K. J. Meech and J. H. Elias (1984). *Astron. J.* **89**, 1587.

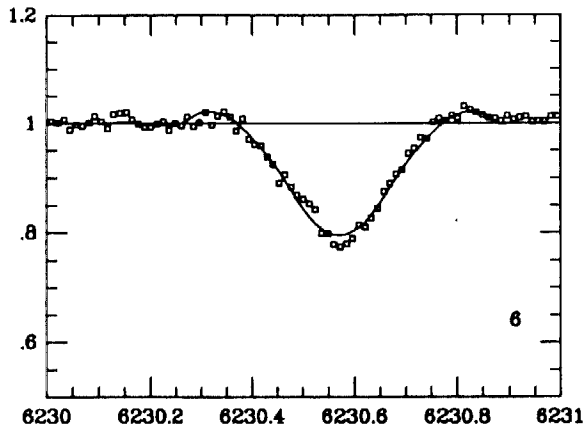
French, R. G., Elliot, J. L., and Levine, S. E. (1986). *Icarus* **67**, 134.

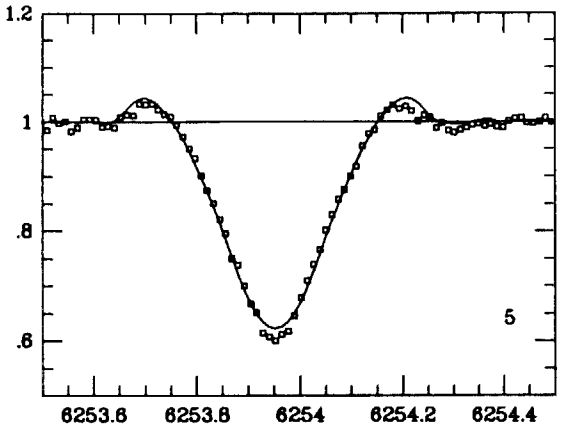
Gresh, D. L., Marouf, E. A., Tyler, G. L., and Rosen, P. A. (1989). *Icarus* **78**, 131.

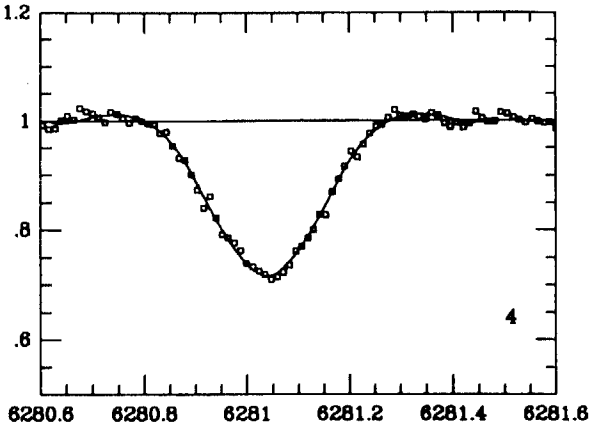
Fig. 1. Ratios of equivalent depths for Voyager PPS (PPS1 = β Per occ'n; PPS2 = σ Sgr occ'n), UVS and RSS (X-band and S-band) data, plus ground-based data at 2.2 μm. Note that the 2.2 μm/3.6 cm and 13 cm/3.6 cm ratios are near unity, while the PPS/3.6 cm and UVS/3.6 cm ratios are near 0.5, due to the 50% relative extinction efficiency for spacecraft stellar occultations (Cuzzi 1985). No intrinsic wavelength dependence in the equivalent depths is seen, suggesting the dominance of large ring particles ($r \gtrsim 1$ cm).

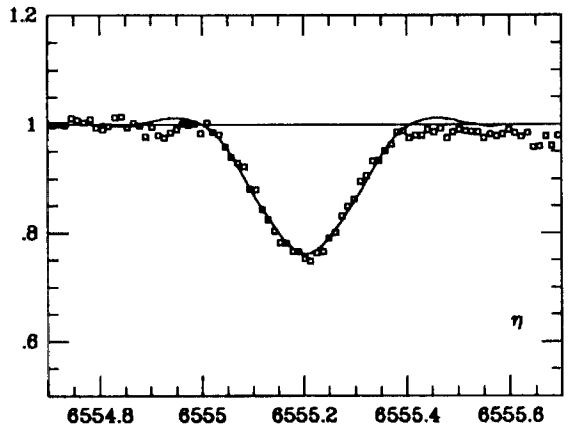
Fig. 2. Occultation profiles of the eight narrow Uranian rings, obtained from a stellar occultation in May 1985, together with least-squares fitted diffraction models. Note the diffraction fringes on rings 5 and γ.

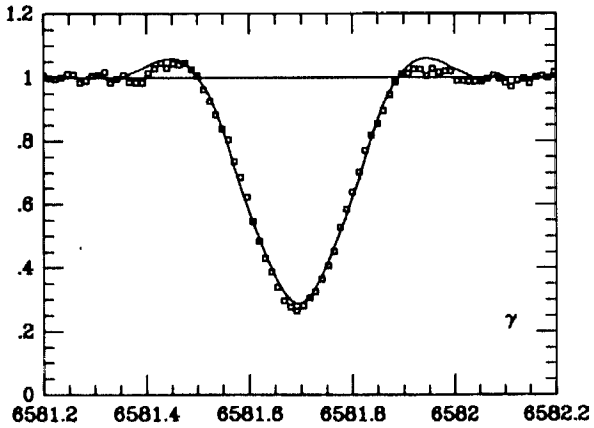

Equivalent Depth Ratios
UVS / X band
PPS2 / X band
PPS1 / X band
2.2μm / X band
S band / X band
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
37
39
41
43
45
47
49
51
Radius, km (x10^3)

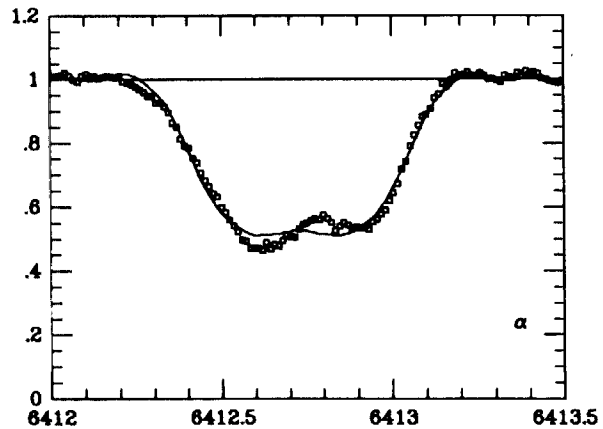

1.2
1
.8
.6
6
6230
6230.2
6230.4
6230.6
6230.8
6231

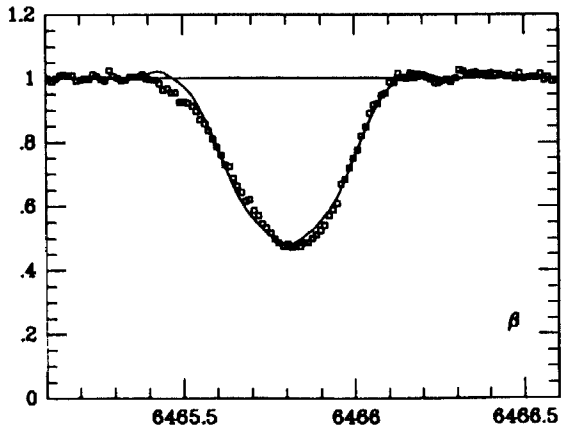

1.2
1
.8
.6
5
6253.6
6253.8
6254
6254.2
6254.4

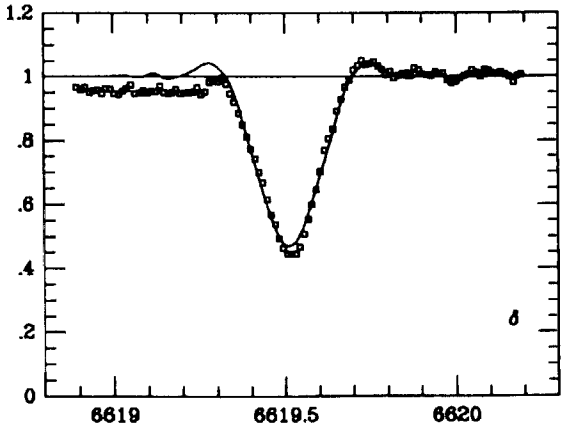

1.2
1
.8
.6
4
6280.6
6280.8
6281
6281.2
6281.4
6281.6


1.2
1
.8
.6
η
6554.8
6555
6555.2
6555.4
6555.6


1.2
1
.8
.6
.4
.2
0
γ
6581.2
6581.4
6581.6
6581.8
6582
6582.2


1.2
1
.8
.6
.4
.2
0
α
6412
6412.5
6413
6413.5


1.2
1
.8
.6
.4
.2
0
β
6465.5
6466
6466.5


1.2
1
.8
.6
.4
.2
0
δ
6619
6619.5
6620